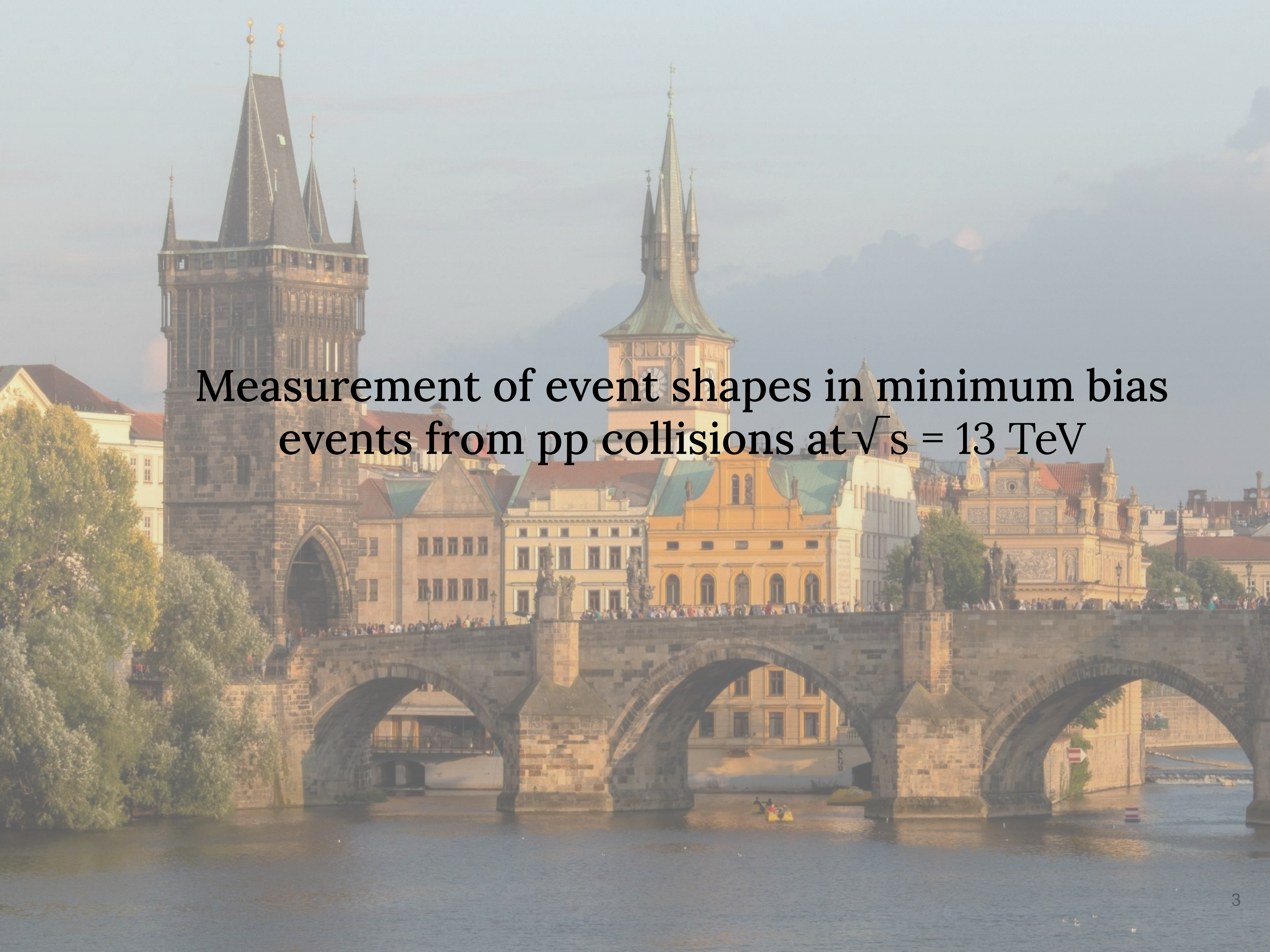
Measurement of Event Shape Variables in pp Collision

Saikat Karmakar
National Taiwan University, Taipei, Taiwan
on behalf of the CMS collaboration
ICHEP2024, July 18, 2024

Outline

➔ The talk is based on three Standard Model results from CMS:

- Measurement of event shapes in minimum bias events from pp collisions at 13 TeV (CMS-PAS-SMP-23-008) New
- Measurement of azimuthal correlations among jets and determination of the strong coupling in pp collisions at $\sqrt{s}$ = 13 TeV (arXiv:2404.16082)
- Measurement of the primary Lund jet plane density in proton-proton collisions at $\sqrt{s}$ = 13 TeV(10.1007/JHEP05(2024)116)



Measurement of event shapes in minimum bias events from pp collisions at $\sqrt{s}$ = 13 TeV

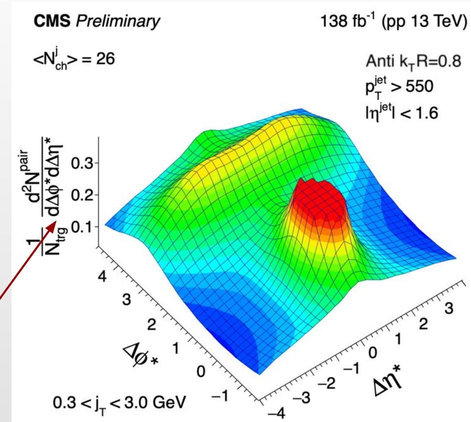
Motivation:

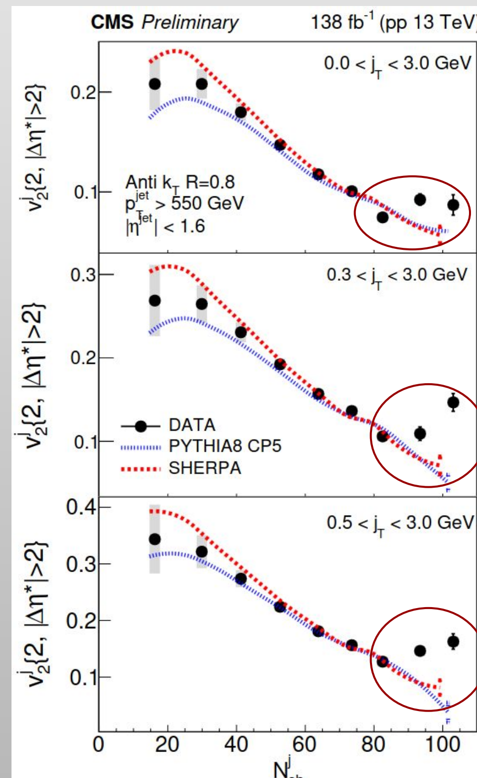
New

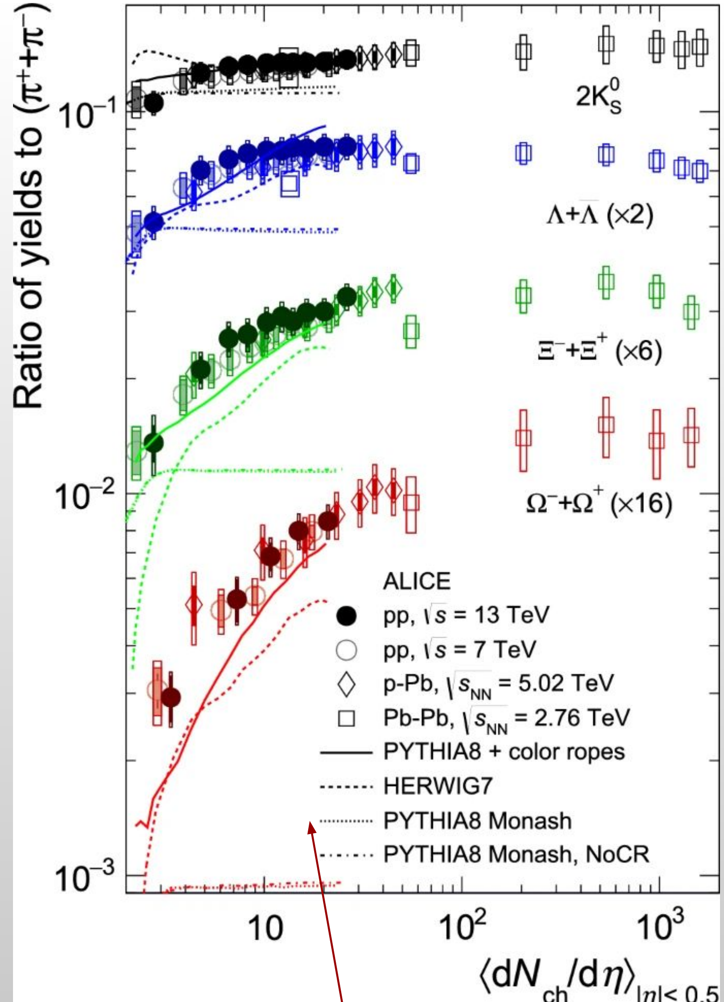
- ➔ Existing observation of unexpected effects in event shapes

Unexpected particle production across η, with ΔΦ ~ 0 in high multiplicity jets

The data-MC difference quantified by single-particle elliptic anisotropy







Increase in strange particle as a function of particle multiplicity → not predicted by MC

Event Selection:

New

Analysis is performed using charged hadrons without clustering into jets:

- ➔ A basic selection on PV: within ±2 (±24) cm around the nominal interaction point along transverse (longitudinal) beam direction
- ➔ Track p_T>0.5 GeV and $|\eta|$<2.4

Observable Measured:

- ❑ **Particle multiplicity:** N
- ❑ **Total invariant mass:** √s
- ❑ **Sphericity:** measure of how isotropically the momenta are distributed
- ❑ **Thrust:** measure of how highly collimated the momenta in an event along one particular axis
- ❑ **Broadening:** measure of the fraction of energy perpendicular to the thrust axis
- ❑ **Transverse sphericity:** the sphericity in the transverse plane
- ❑ **Transverse thrust:** the thrust in the transverse plane
- ❑ **Isotropy:** measure of how isotropically energy is distributed in an event

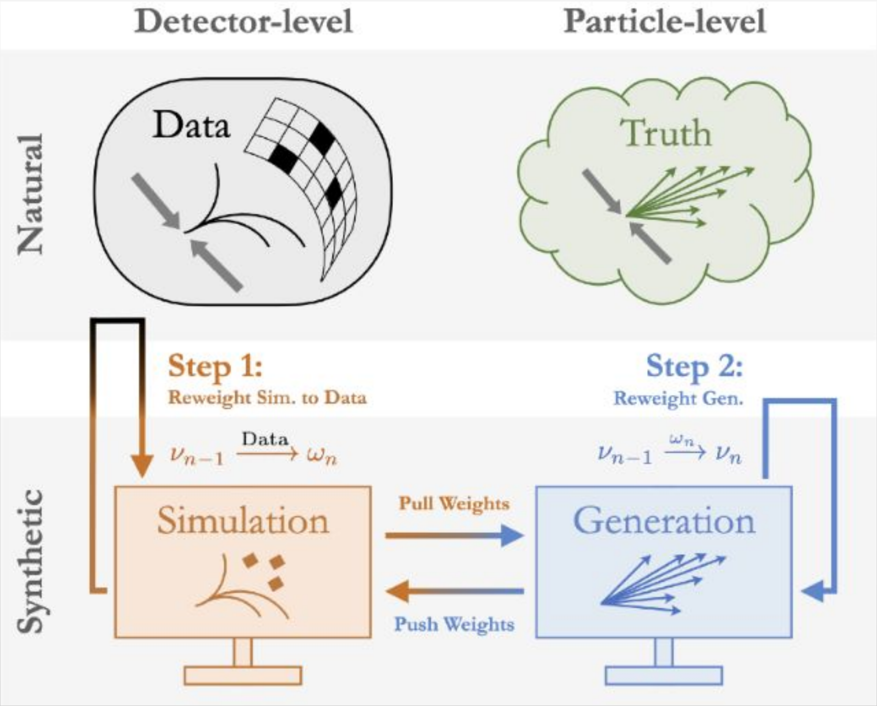
$$S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i |\vec{p}_i|^2}$$

$$\tau = 1 - max_{\vec{n}} \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i |\vec{p}_i|^2}$$

Saikat Karmakar saikat.karmakar@cern.ch

Unfolding Using Machine Learning

New



Multifold:

- **Input:** values of 8 observables for every event in simulation and data
- **Output:** reweighted simulated events approximating data
- Result are **unbinned** weighted events

Two steps of unbinned reweighting:

- Weight MC to data at detector level
- Weight original MC to reweighted MC at generator level
- Extra 2 steps added to deal with the selection efficiency and signal acceptance

➔ Repeat in iterations

➔ Iteration acts as the regularization

First time used in CMS

Ref: https://arxiv.org/abs/1911.09107
https://arxiv.org/abs/2105.04448

Uncertainty estimation

New

Track reconstruction efficiency (~1.7%):

1. Randomly drop 2.1%(1%) tracks with p_T<20 GeV (>20 GeV) in nominal MC
2. weight the nominal MC to Step1 output at particle- and detector-level

Mismodeling of the migration (~1.6%):

Derive the templates by weighting nominal MC to alternative MC at the particle-level

→ ML-based unbinned weighting → output: weighted nominal MC events

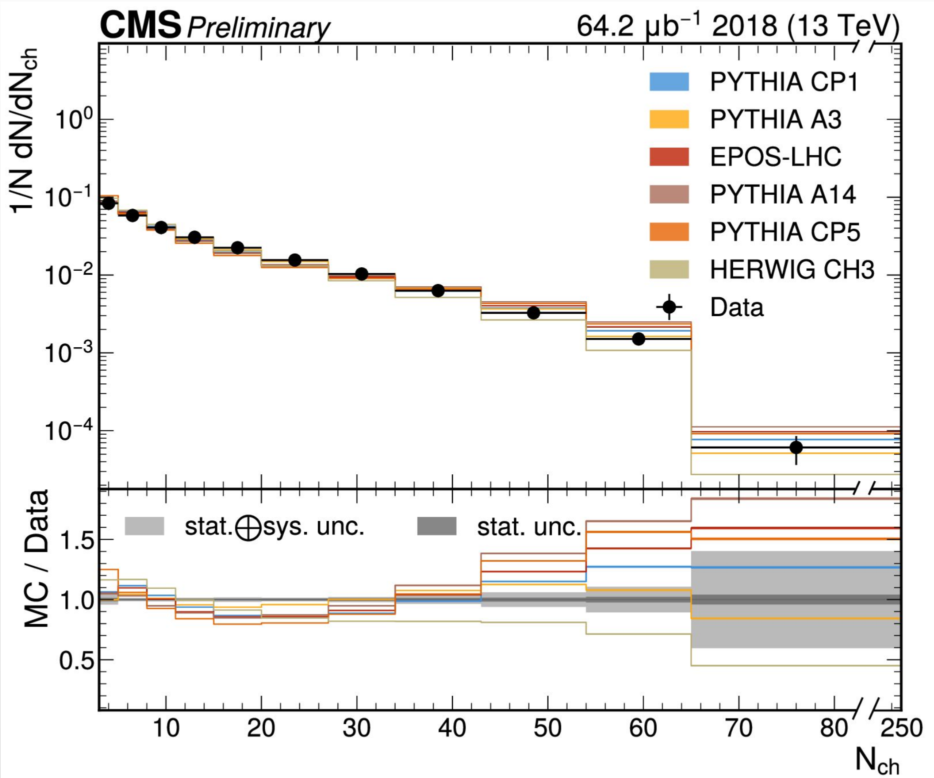
- Do unfolding with same particle-level distribution as alternative MC
- keeps the gen. → reco. migration of the nominal MC

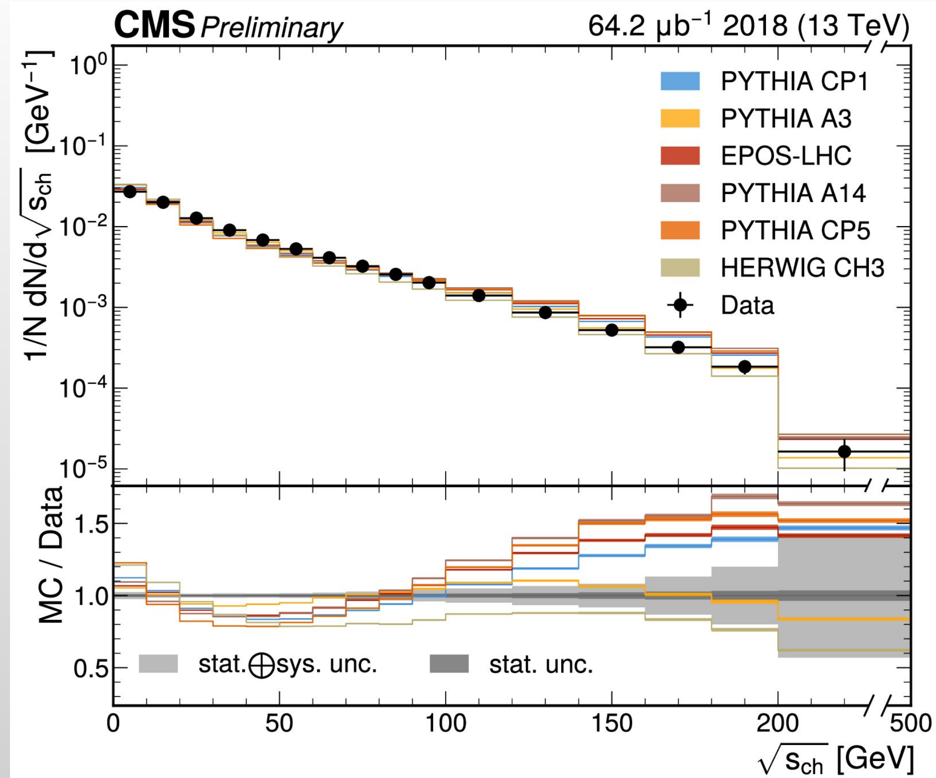
Bias from regularization (~1.2%):

Alternative simulated samples which is used as inputs to the unfolding.

Result

New



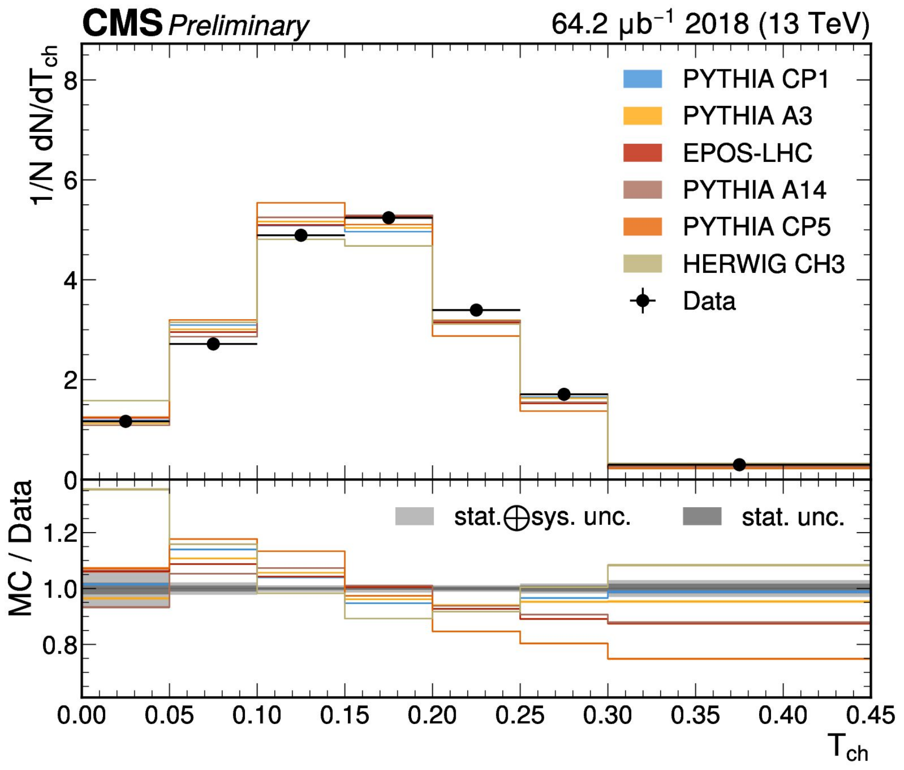


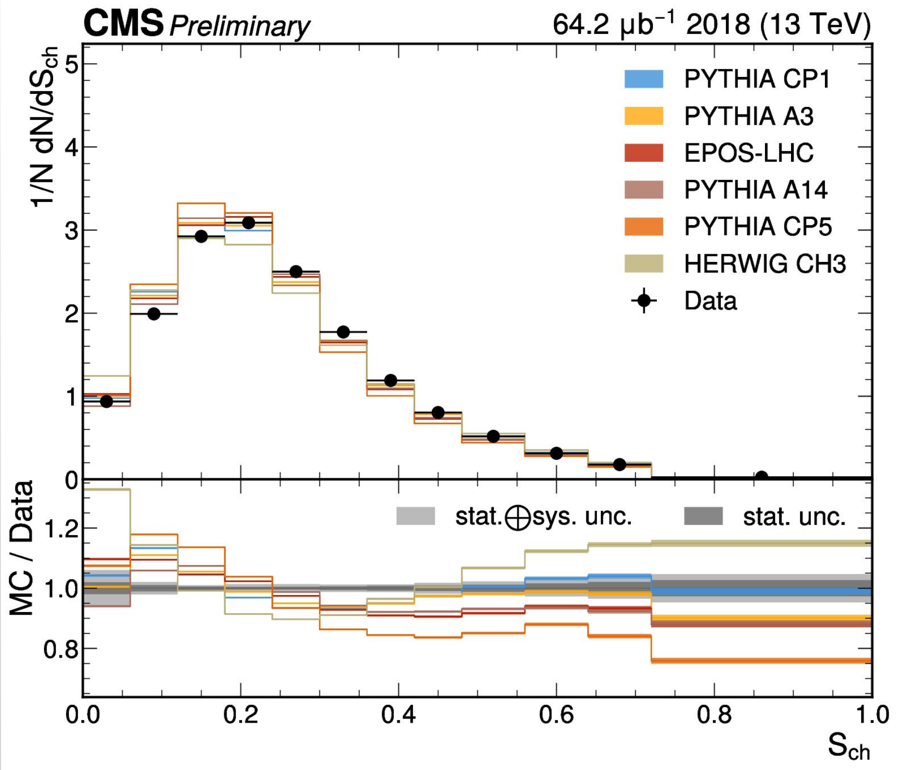
For number of charged particles and their invariant mass, all generator:

- Over estimate data at low multiplicity region
- Under estimate at intermediate value
- Consistency is broken at high multiplicity and mass

Result

New



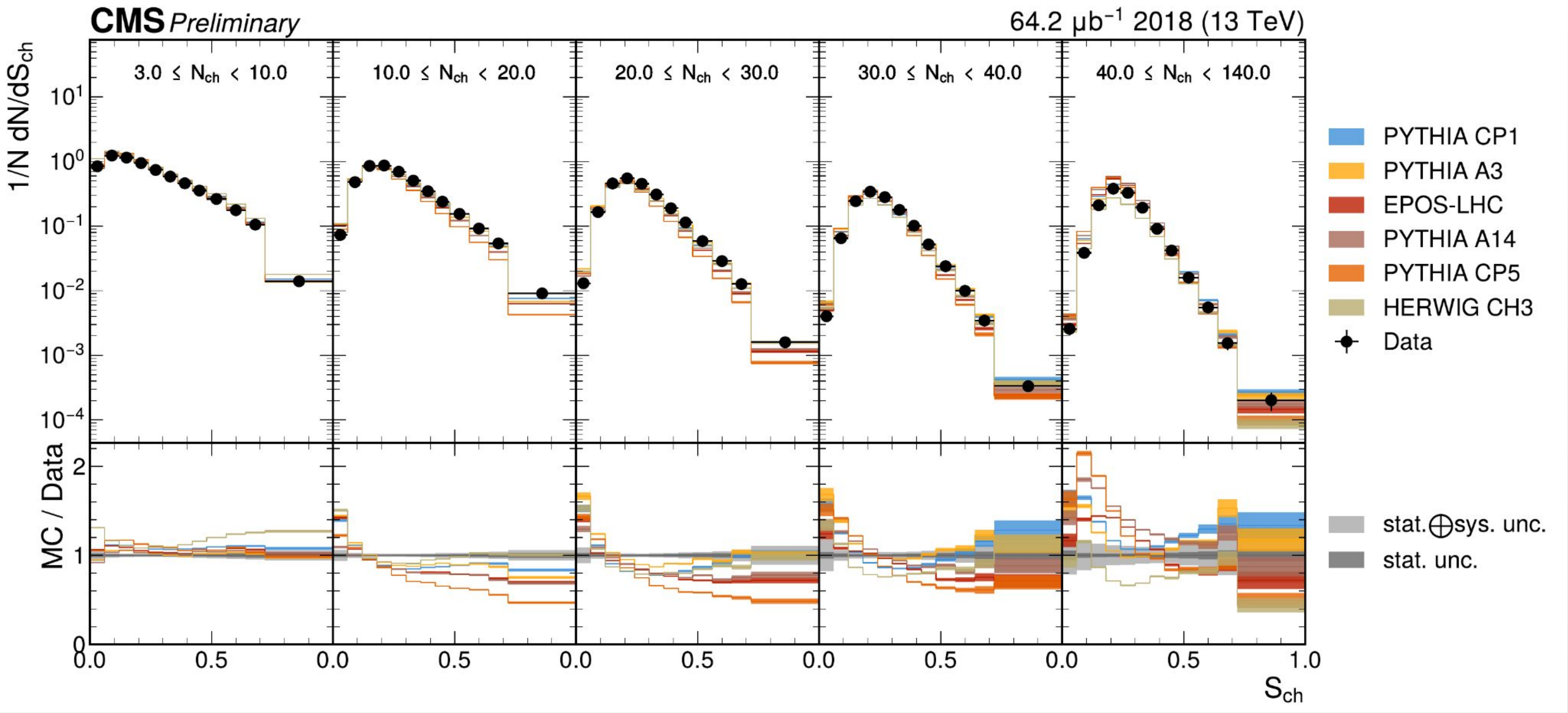


Other event-shape observables show a consistent trend:

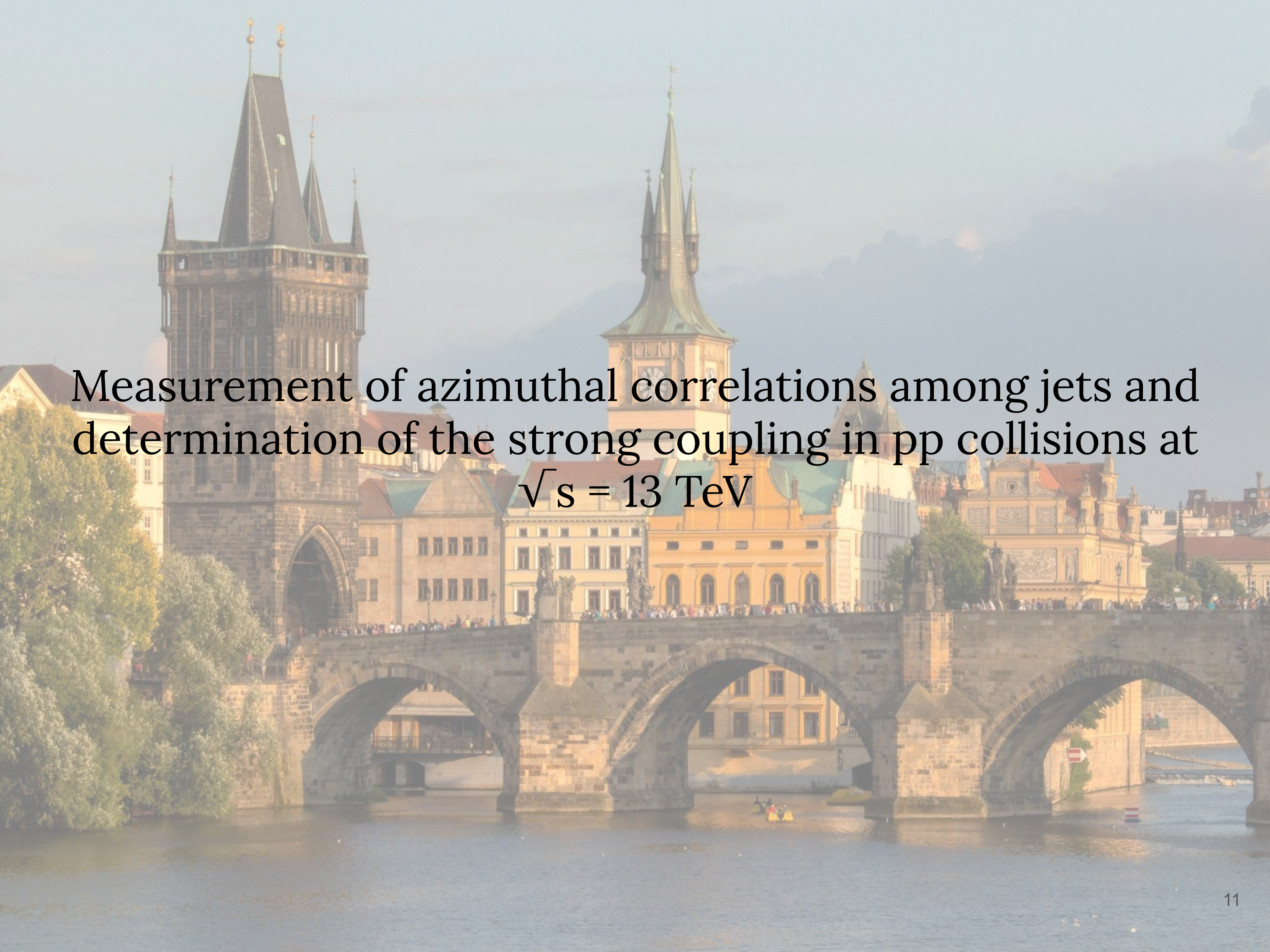
- The unfolded data are more isotopic than the simulation

Result: Interpretation

New

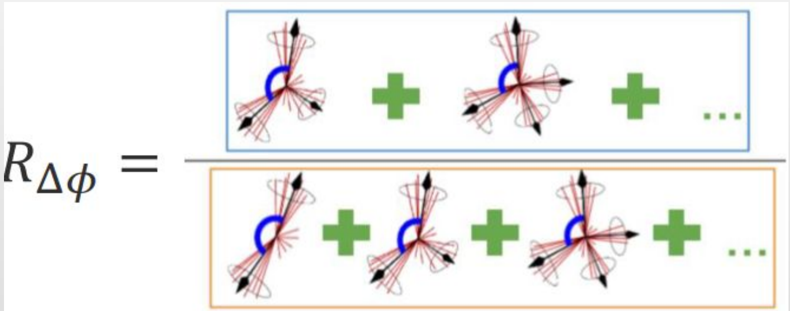


- Data-MC discrepancy is largest in the middle N_{ch} region
- Mismodeling is observed for all event shape variables
- Discrepancy sustains under variations of **PDF, generator, UE tune, color-reconnection models**, α_S**(FSR)**
- unfolded results are provided for further theoretical interpretation



Measurement of azimuthal correlations among jets and determination of the strong coupling in pp collisions at $\sqrt{s}$ = 13 TeV

$$R_{\Delta\phi}(p_T) = \frac{\sum_{i=1}^{N_{jet}(p_T)} N_{nbr}^{(i)}(\Delta\phi, p_{Tmin}^{nbr})}{N_{jet}(p_T)}$$



- Denominator: No. of all jets
- Numerator: No. of neighbouring jets of jet i within the interval 2π/3< $\Delta\phi$< 7π/8
- Chosen interval selects only 3+ jets in the numerator and all jets in the denominator

$$R_{\Delta\phi} \sim \frac{\alpha_S^3}{\alpha_S^2} \sim \alpha_S(m_Z)$$

➔ Several effects considered for extraction of α_S :

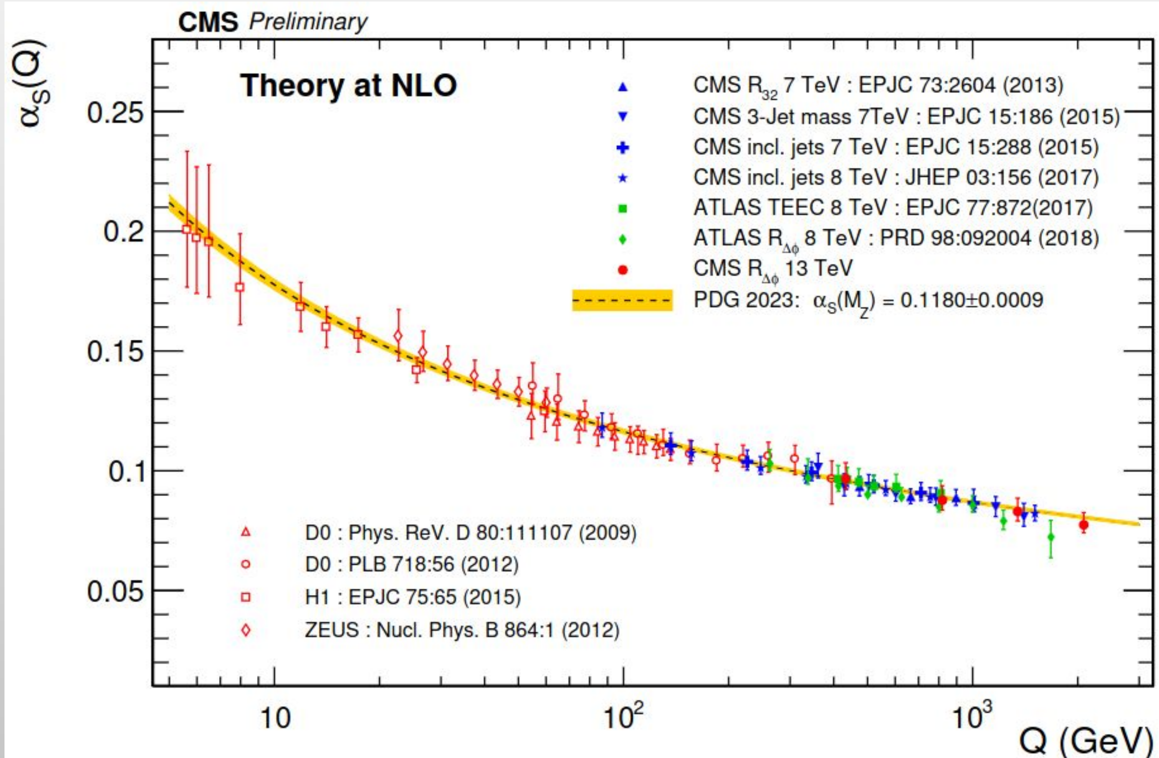
- perturbative QCD (pQCD) calculations using NLOJet++ within fastNLO
- Non-perturbative (NP) effects estimated from Monte Carlo

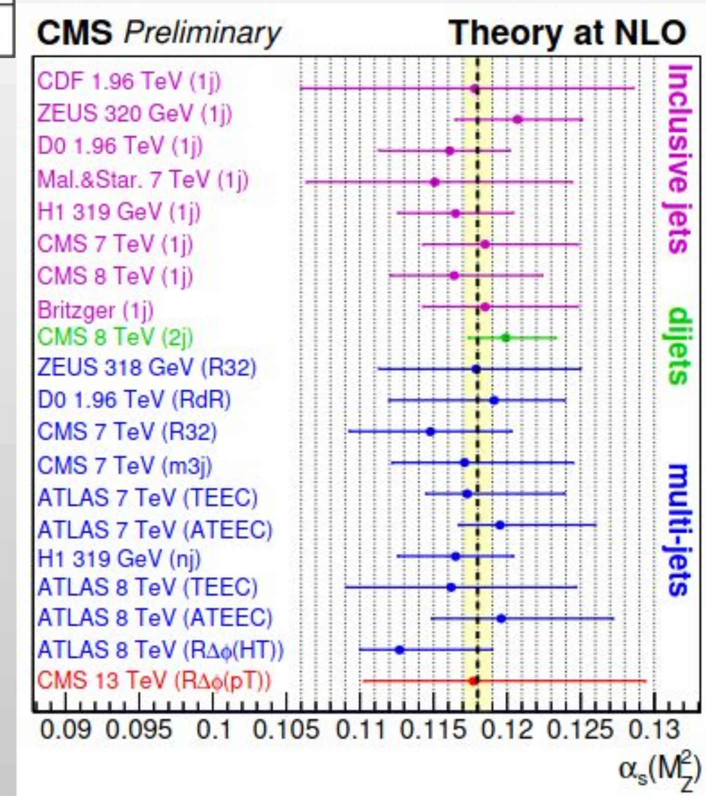
$$C^{NP} = \frac{\sigma^{PS+NPI+HAD}}{\sigma^{PS}}$$

- NLO electroweak (EW) effects from SHERPA + RECOLA (0.2-5%)

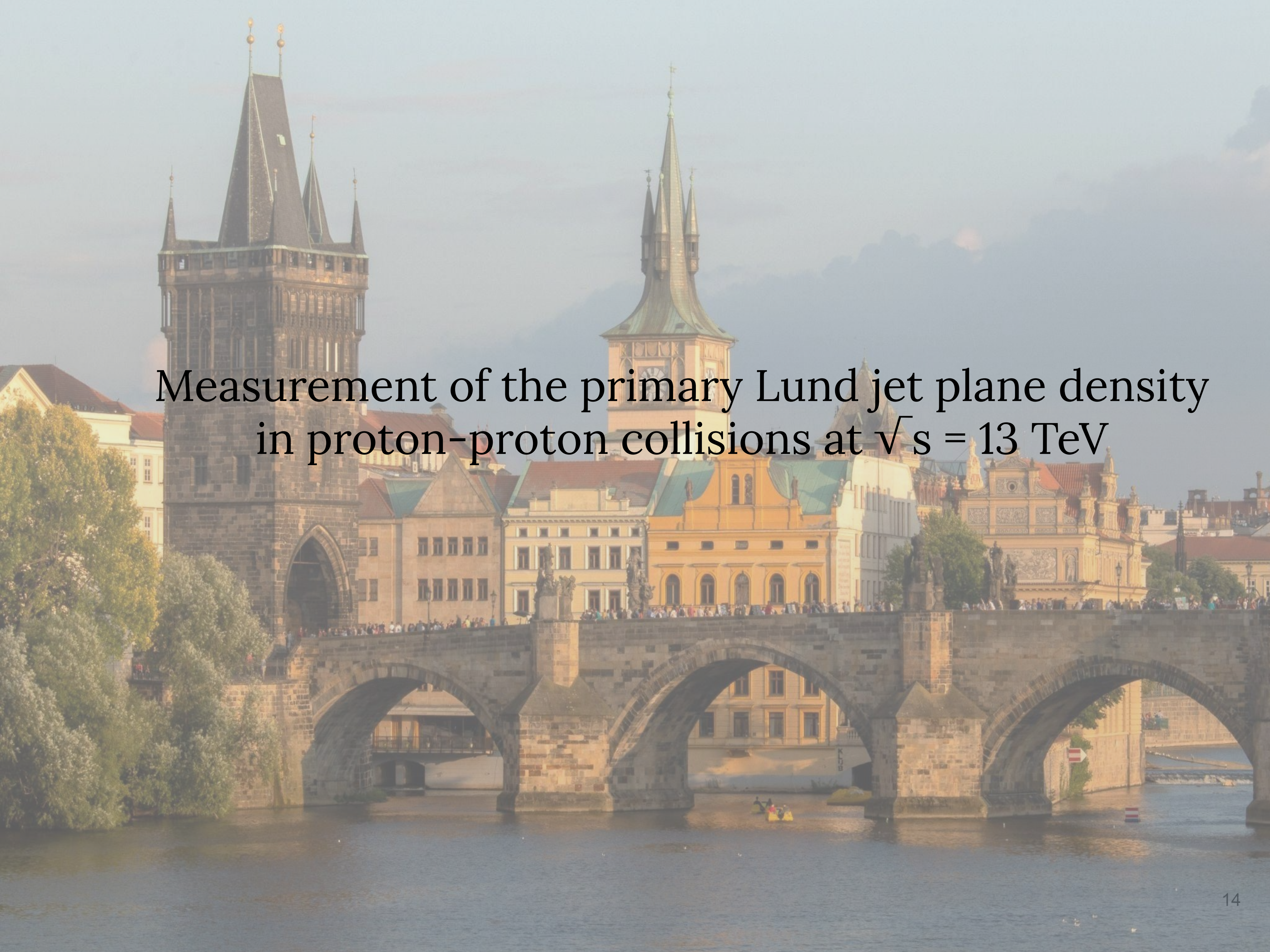
For more details: See talk by Paris Gianneios

PDF set	$\alpha_S(M_Z)$	Exp	NP	PDF	EW	Scale	Total	χ^2/n_{dof}
ABMP16	0.1197	0.0008	0.0007	0.0007	0.0002	$^{+0.0043}_{-0.0042}$	$^{+0.0045}_{-0.0044}$	16/16
CT18	0.1159	0.0013	0.0009	0.0014	0.0002	$^{+0.0099}_{-0.0067}$	$^{+0.0101}_{-0.0070}$	19/16
MSHT20	0.1166	0.0013	0.0008	0.0010	0.0003	$^{+0.0112}_{-0.0063}$	$^{+0.0114}_{-0.0066}$	17/16
NNPDF3.1	0.1177	0.0013	0.0011	0.0010	0.0003	$^{+0.0114}_{-0.0068}$	$^{+0.0116}_{-0.0071}$	20/16





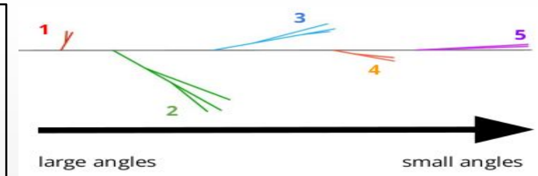
- ❑ analysis results are consistent with the energy dependence predicted by the RGE and no deviation is observed up to ~ 2.081 TeV: highest value so far obtained.

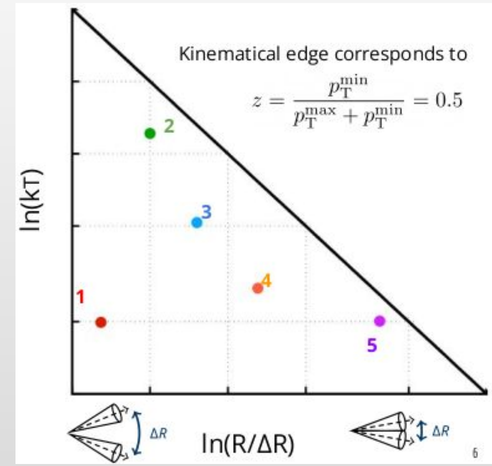


Measurement of the primary Lund jet plane density in proton-proton collisions at $\sqrt{s}$ = 13 TeV

Lund Jet Plane: 2D representation of 1->2 jet splitting with

- Splitting angle: $\Delta R = \sqrt{(y_{hard} - y_{soft})^2 + (\phi_{hard} - \phi_{soft})^2}$
- Transverse momentum: $k_T = p_T \Delta R$
- Represented in **log**(k_T) and **log**($1/\Delta R$) plane





Main objective is to measure jet-averaged density of emissions

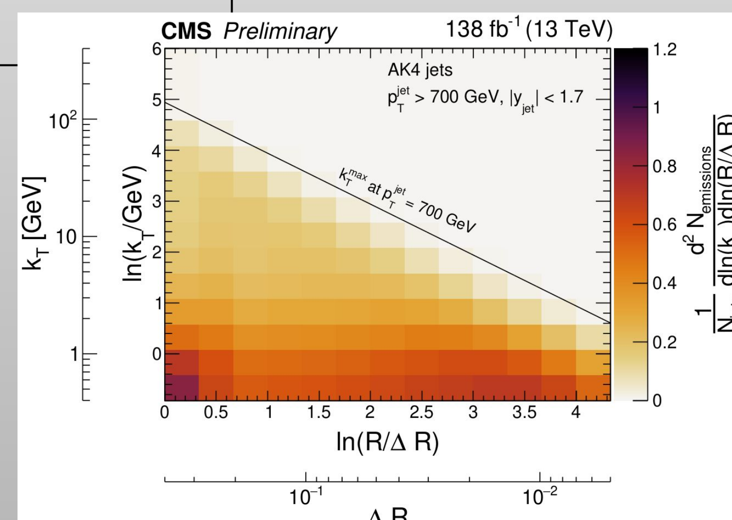
$$\frac{1}{N_{jets}} \frac{d^2 N_{emission}}{dln(k_T) dln(R/\Delta R)} \simeq \frac{2}{\pi} C_R \alpha_S(k_T)$$

Analysis performed using AK4 and AK8 jets:

- First, constituents of anti-k_T jets are reclustered using Cambridge/Aachen algorithm
- Then CA jets are declustered iteratively until single core is reached

Dominant syst. Unc.
PS and hadronization modeling, tracking efficiency

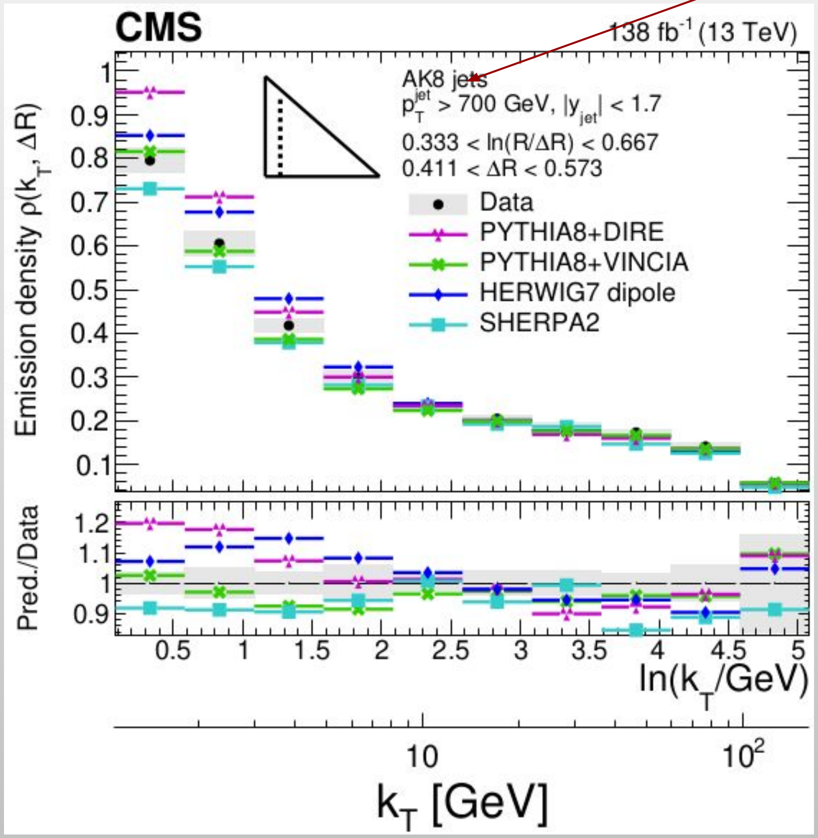
Total Unc. 2-7%
(20% at the edge of the plane)

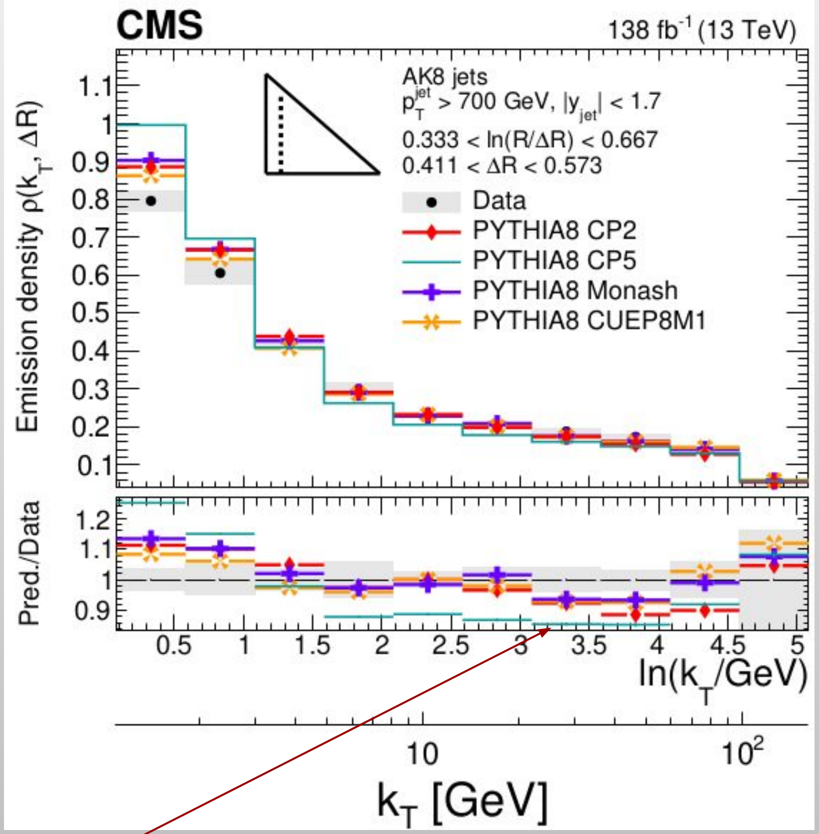


Result

Compared with different MC and different setup of PS/Hadronization, PDF and α_S

- ❑ Pythia8 with DIRE and VINCIA shower model
- ❑ Herwig7 dipole shower, Sherpa



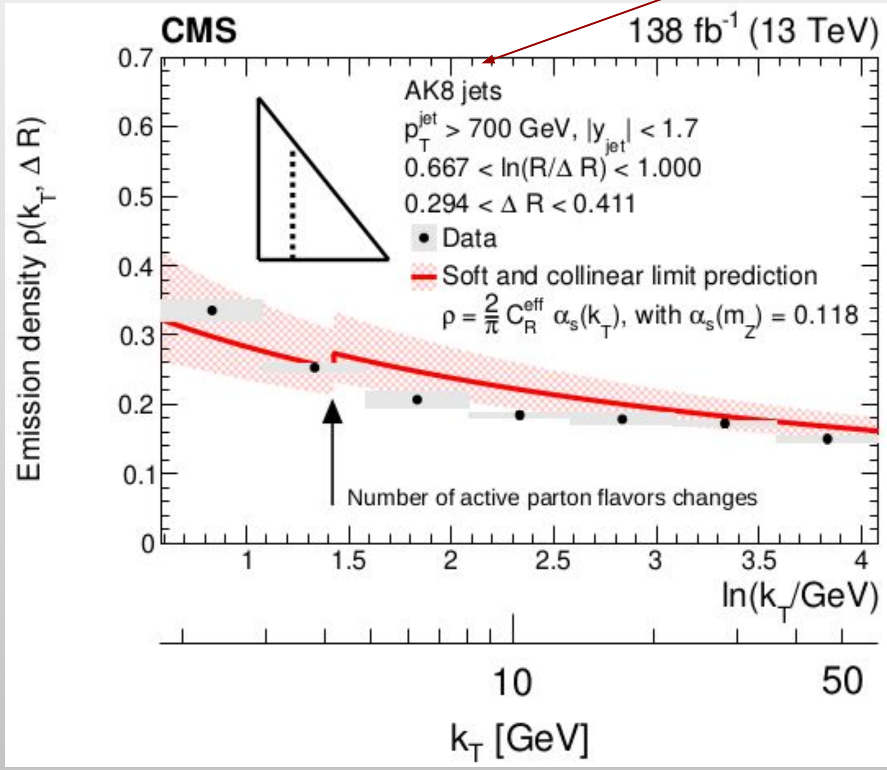


Comparison to different Pythia8 tunes

- ❑ important to test accuracy and better tune MC generators

Result

Compare results also with analytical prediction from perturbation theory
- ❑ Shows effect of running of α_S
- ❑ Compare with soft and collinear limit prediction



Observations are consistent with other measurements with of generalized angularities in Z+jets and di-jet events.

Unfolded results are provided, which can be used:
- ❑ as an input to improve the description from event generators
- ❑ for future developments of parton showers

Conclusion

- CMS provided several precision measurements in QCD related topics with Run 2 data

- Presented only the most recent ones, which is a fraction of all results
  - Measurement of event shapes in minimum bias events
  - Measurement of azimuthal correlations among jets and determination of the strong coupling
  - Measurement of the primary Lund jet plane density

- Run 3 is on its way

- Many more exciting results are coming in the next months

- For the new CMS results please keep an eye on: CMS Public Results

Thank You

Back up